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VERY FAST, HIGH PEAK POWER PLANAR TRIODE AMPLIFIERS FOR DRIVING OPTICAL GATES*

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ABSTRACT

Recent extensions of the peak power capabilities of planar triodes have made possible the latter's use as very fast pulse amplifiers, to drive optical gates within high-power Nd:glass laser chains. These pulse amplifiers switch voltages in the 20 kV range with rise times of a few nanoseconds, into crystal optical gates that are essentially capacitive loads.

This paper describes a simplified procedure for designing these pulse amplifiers. It further outlines the use of bridged-T constant resistance networks to transform load capacitance into pure resistance, independent of frequency.

Introduction

Many optical gates in the Shiva laser system at the Lawrence Livermore Laboratory are Pockels cells. An approximate electrical model of the Pockels cell is a capacitor,[1] whose capacitance must be charged very quickly to optimize the rise time of the cell. The planar triode is a small, rugged, microwave vacuum triode[2] designed for operation to 3 GHz. A cutaway drawing of a class of these centimeter-wave planar tubes is shown in Fig. 1. The three tube types of most interest to us as Pockels cell drivers are shown in Table 1. Note that the 8941 and the X2172 both have peak power capabilities approaching the 500 kW for short (50-nsec) pulses.

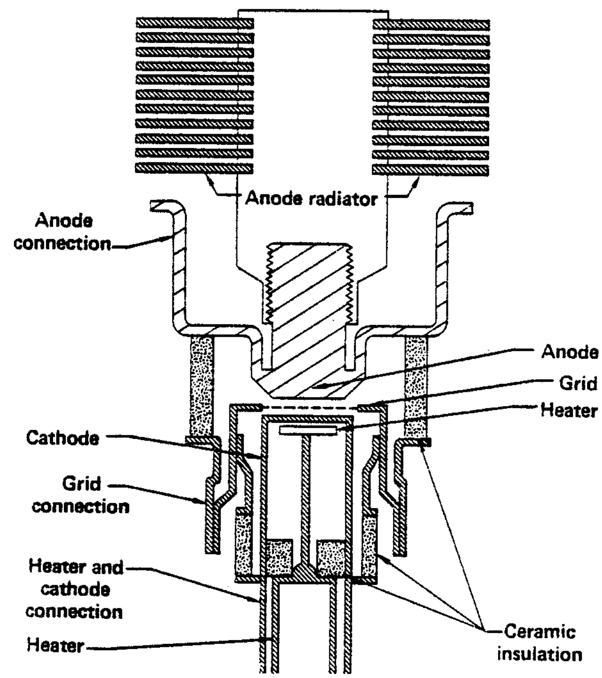

Fig. 1: Electrode arrangement of a planar triode

Eimac Type†	Plate Voltage	Max. Current	C Input	C Output	Mu
8940	4.5 kV	36 A	16 pf	0.11 pf	65
8941	15 kV	36 A	14 pf	0.11 pf	200
x2172	25 kV	36 A	16 pf	0.2 pf	500

Table 1. Maximum ratings of some planar triodes.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore Laboratory under contract no. W-7405-Eng-48.

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Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **JUN 1979**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE
Very Fast, High Peak Power Planar Triode Amplifiers For Driving Optical Gates

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lawrence Livermore Laboratory Livermore, California 94550

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License

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Recent extensions of the peak power capabilities of planar triodes have made possible the latter's use as very fast pulse amplifiers, to drive optical gates within high-power Nd:glass laser chains. These pulse amplifiers switch voltages in the 20 kV range with rise times of a few nanoseconds, into crystal optical gates that are essentially capacitive loads. This paper describes a simplified procedure for designing these pulse amplifiers. It further outlines the use of bridged-T constant resistance net,vorks to transform load capacitance into pure resistance, independent of frequency.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Circuit Development

To minimize the Miller effect of the grid to cathode capacitance, the planar triode is generally used in the grounded grid configuration. This requires that the preceding stage be capable of supplying the full plate current as well as any current drawn by the grid. The common cathode connection of the tube can provide current gain, and a bridged-T network employed in the grid circuit overcomes the bandwidth limitation of the common cathode configuration. This greatly reduces the current drive requirement of the preceding stage.

Ginzton et al.[3] describe a negative mutual inductance circuit, termed a bridged-T connection, which is used on broad-band distributed amplifiers. This circuit can mask the input capacitance of a tube or Pockels cell. Figure 2 shows the bridged-T network and its various equivalents. Choosing the values from Fig. 2(c), we can show that the image impedance is constant, resistive, and frequency independent. This eliminates the need for terminating half sections and permits us to terminate the line with a resistor. The cutoff frequency across the midshunt capacitance in terms of Z_o, L, and C, is shown in the appendix (Fig. 6).

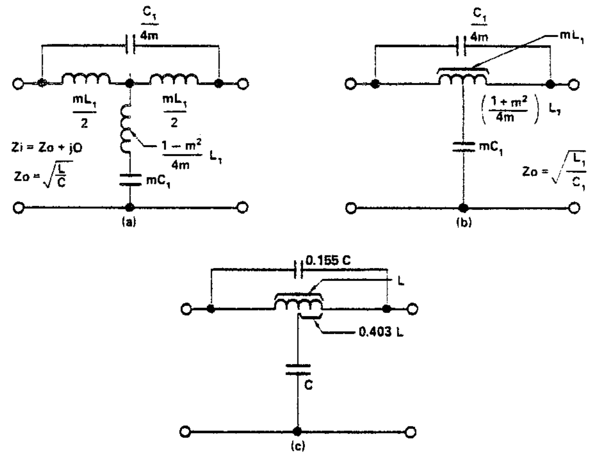


Fig. 2: (a) Constant resistance bridged-T networks
(b) The mid-shunt inductance is obtained from the mutual inductance of this coil
(c) m = 1.27 yields an optimum gain bandwidth network

Triode Pulse Amplifier

The schematic of a pulse amplifier circuit to drive a 10-mm aperture Pockels cell is shown in Fig. 3. The Eimac 8941 planar triode is configured as a common cathode amplifier, biased just beyond cutoff. The end-to-end capacitance of the Pockels cell is 15 pF. Choosing Z_o as 130 Ω, and using the design charts in the appendix, L = 0.25 μH and the cutoff frequency across the cell is ∿ 145 MHz. A

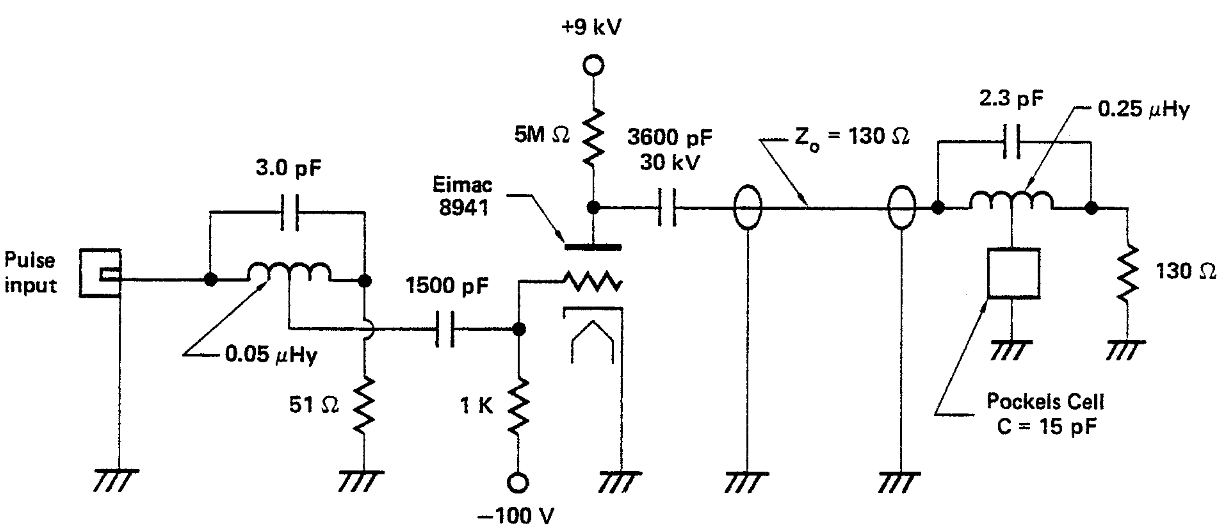


Fig. 3: Planar triode amplifier

similar network is designed for the grid circuit with Z_o equal to 50 Ω.

The load impedance for the planar triode is then 130 Ω resistive, and for a half-wave voltage at the Pockels cell of 3500 V, the peak current is 26.9 A. A load line for this case is shown on the constant current characteristics for the tube in Fig. 4. It requires that the grid be driven about 135 V positive, to achieve the necessary plate voltage swing and peak current. The voltage pulse measured at the output of this amplifier into an attenuator as shown in Fig. 5.

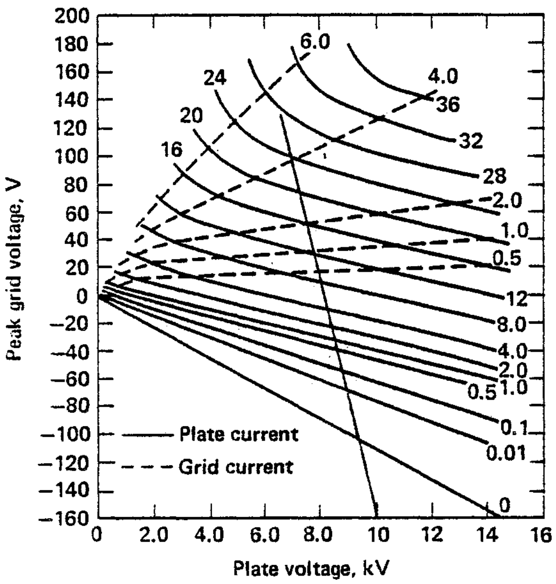
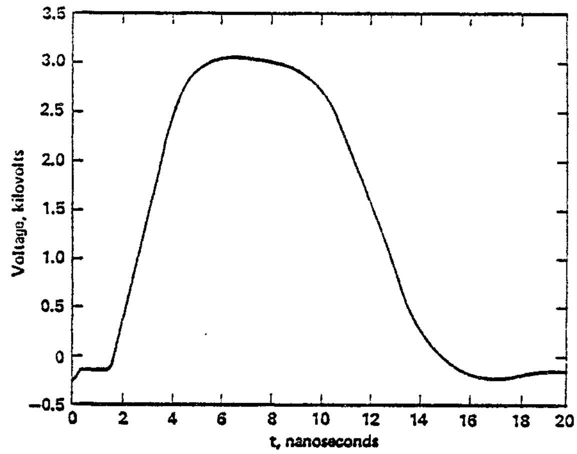


Fig. 4: The constant current characteristic of a planar triode.

From Fig. 4, the grid will draw almost 5.5 A, when it is driven positive by 135 V. The driver for the grid is an avalanche-transistor transmission line pulser that does not work into this changing load too well; so the input rise time to the triode is limited to about 2.5 nsec. This also means that when the tube grid draws current, the bridged-T network is no longer balanced; so at this time a reflection will be sent toward the driver.

The combination of high peak power and large bandwidth requires the circuit to be laid out care-



Scale - Horizontal: 5 nsec/div
Vertical: 1000 V/div

Fig. 5: Output of the planar triode amplifier

fully. It is essential that tube lead inductances be kept low, so that the resonance associated with these electrodes will lie well above the operating band of the amplifier. Many small capacitors connected in parallel, and mounted on a low-inductance printed circuit board, serve as a by-pass or coupling network. Low-value series resistors, connecting decoupling capacitors, are an effective way to isolate the modes of the B+ supply wiring from the amplifier circuitry.

Discussion

Let us summarize our design of a planar triode amplifier for broad-band performance and consider the various tradeoffs involved. Normally, the load is specified first and, if it can be modeled as a capacitor it can be broad-banded in a bridged-T configuration by using the design charts in the appendix; this sets a cutoff frequency and an impedance level. The bridged-T network can be used up to ∿ 400 MHz. Above this figure, the small value of the components make them difficult to fabricate. The voltage necessary at the load and the impedance of the load determine the tube to be used. The cutoff frequency of the load sets the parameters of the broad-banded grid circuit. Careful component layout then assures optimum amplifier performance.

We have used the techniques presented here to design a pulse amplifier for driving a 10-mm Pockels cell. The amplifier performed as predicted. Its output characteristics are: 3600 V into 130 Ω with 2.5-nsec rise time, 3-nsec fall time, and pulse width of 8-9 nsec. The jitter is less than 100 psec.

Appendix[4]

Of the various lumped-constant lines for the anode and grid circuits studied by Ginzten et al.[3], the bridged-T network provides the highest-gain bandwidth product. For a given gain, the bridged-T line provides about twice the bandwidth of the constant-K line.

We obtain the midshunt inductance from the mutual coupling between the two halves of the coil, as shown in Fig. 2(b). If we choose m to be 1.27, the inductance to the midpoint of the coil must be 40.3% of the total coil inductance.

By using the equation

$$L = \frac{r^2 n^2}{9r+10\ell} \quad \mu H$$

where n is the number of turns, and ℓ and r are the length and radius of the coil, respectively, the correct coupling results when the length of the coil is 1.35 times the coil's diameter.

The output voltage, taken across capacitor C in Fig. 2(c), has a cutoff frequency

$$F_1 = \frac{1}{\pi\sqrt{LC}}$$

and the characteristic impedance

$$Z_o = \sqrt{\frac{L}{C}}$$

Figure 6 is a design chart for the bridged-T constant resistance network of Fig. 2(c), with the values of L and C plotted as functions of Z_o and F_1. Figure 7 is a design chart for the inductor in this network.

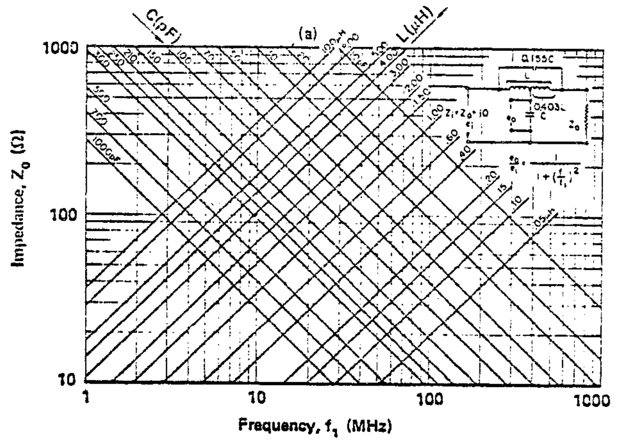


Fig. 6: Design chart for bridged-T network of Fig. 3.

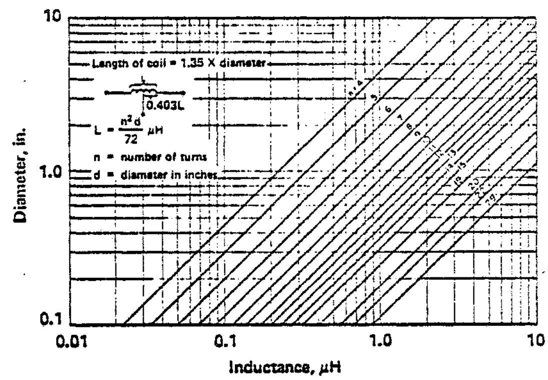


Fig. 7: Design chart of inductance for bridged-T network of Fig. 3.

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